Assay of Radioactivity Content of Cavern Walls for the Deep Underground Neutrino Experiment (DUNE) at Sanford Lab

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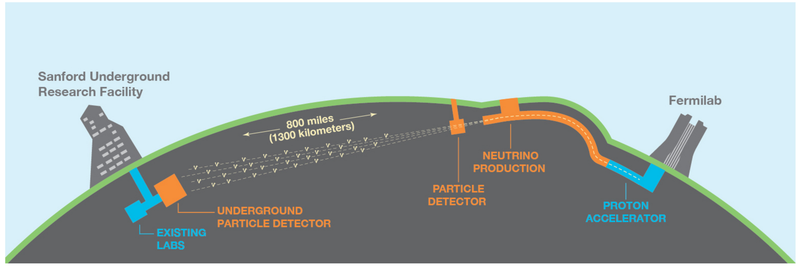
Authors: *Faith Beall*, *Dr. Juergen Reichenbacher (Advisor at SD Mines)*, James Haiston, Layne Tieszen, Madan Timalsina and Serenity Engel

About DUNE:

At Sanford Lab in Lead, South Dakota, rock excavation is underway to make room for a 40 kton massive liquid argon detector to precisely study neutrinos from an accelerator at Fermilab/Chicago, from galactic supernovae explosions and from the Sun. Neutrino interactions in the detector are rare and can easily be mimicked by radioactivity from the cavern walls and materials in the cryostat/detector. Minimizing the interference with neutrino induced signals, it is thus paramount to control radiological backgrounds such that DUNE will achieve all of its physics goals. Assaying, controlling and mapping the ambient background radiation in the cavern walls and the materials in the cryostat/detector is hereby key and provides crucial input for detailed and realistic computer simulations of the DUNE neutrino detector.

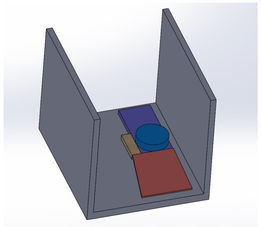


DUNE project. Deep Underground Neutrino Experiment. https://www.dunescience.org/

Germanium Detector ('Rabbit') at SD Mines: Usage for Rock Assays & Maintenance Improvement

Assaying of excavated rock, as well as shotcrete, concrete, cryostat & detector materials has commenced and will continue to take place at the nearby South Dakota School of Mines and Technology with the Rabbit germanium detector employing γ-ray spectroscopy. Many hundreds of samples are expected to be assayed for radiological content. Thus, fast and efficient operation of the Rabbit Ge-detector and user-friendly analysis scripts for sample data are highly desirable. Ge-detectors require to be operated at very low temperatures by means of cooling with liquid nitrogen stored in a dewar which has to be refilled weekly.

To allow for a maximally fast refilling process, design changes were made to the dewar filling station in the lab. A new scale and a custom made and designed ramp result in a faster refilling process, as the external dewar needs to be handled for weighing only once a month instead of weekly.



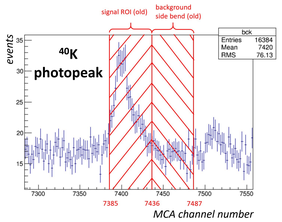
SolidWorks drawing of the layout of the newly designed scale & ramp for the LN2 dewar.

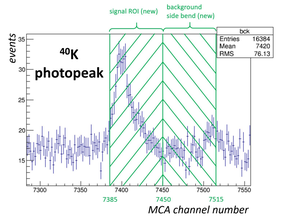
LN2 dewar in lab with the new scale and ramp.

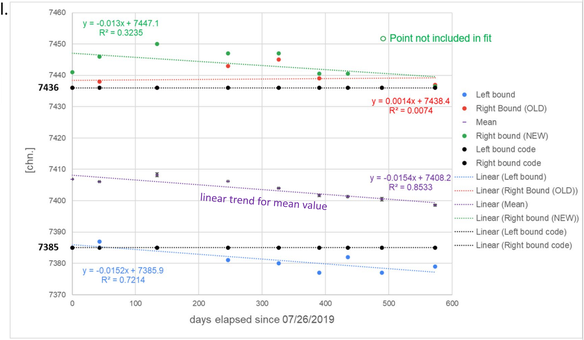
Other side view of LN2 dewar with Ge-detector in view.

Analysis of K-40 γ-Ray Line to Characterize the Ge-Detector's Time Stability:

Ge-detector data taken from July 2019 to February 2021 were used to determine the time dependent stability of the detector's signal response. The full absorption photopeak of the K-40 γ-ray line was utilized as a tracer for the study. In each data set, a Gaussian distribution was fitted to infer the mean, standard deviation and errors for the K-40 peak. The left and right bounds of the signal band, and the mean of the K-40 peak are placed on the graph as function of elapsed days showing the need for a linear time dependent correction. The bounds of the signal and background bands in the analysis code also need to be expanded, due to the bounds of the signal existing outside interval.

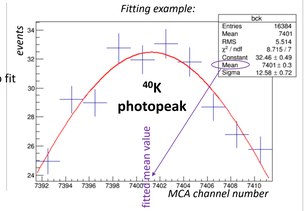






Using ROOT/C++ framework to fit a Gaussian distribution to find the mean, standard deviation and errors for the K-40 peak in each data set:

Fitting example:



Applying and Validating Linear Time Dependent Correction:

A past test sample (from the DUNE Test Blast Site) was re-measured to demonstrate a) reproducibility and b) to validate the time dependent corrections applied to the data (in ROOT/C++ analysis source code). The four most important radioactive isotope signals for relevant radiological backgrounds were utilized to compare both the uncorrected and stability corrected results on the inferred specific activities.

=> Results show **correction is indeed needed** and if applied, all lines yield **very good reproducibility** of results over the course of more than two years!
=> **relative systematic uncertainty only 6.5%** ! (*cf. K-40 specific activities*)

	Ra-226 [Bq/kg]	Pa-234m (U-238) [Bq/kg]	Ac-228 (Th-232) [Bq/kg]	K-40 [Bq/kg]
Sample 3 (TestBlastSite)	145.96 +/- 1.48	61.17 +/- 10.26	19.63 +/- 0.45	376.33 +/- 2.28
Sample 3 (TestBlastSite) Corrected	149.51 +/- 1.48	69.38 +/- 10.27	19.43 +/- 0.45	370.30 +/- 2.27
Sample 3 (TestBlastSite) - Remeasured	146.17 +/- 1.48	75.66 +/- 10.28	17.13 +/- 0.44	312.38 +/- 2.21
Sample 3 (TestBlastSite) - Remeasured & Corrected	144.86 +/- 1.48	74.38 +/- 10.27	17.57 +/- 0.44	345.78 +/- 2.26

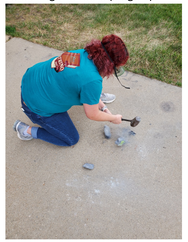
description	Mass of sample [kg]	Mass of sample without bottle (output) [kg]	Livetime [days]	Days elapsed since 07/26/2019	Average days elapsed	Expected mean value (y = -0.0154x + 7408.2) [ch
Sample 3 - Test blast site (04/05/2020)	0.342	0.293	5.8	252	249.1	7404.364012
Sample 3 - Test blast site remeasured (07/22/202	0.342	0.293	5.7	725	722.1	7397.079078
Bck for sample 3 - (3/11/2020)			32.7	227	210.6	7404.956374
Bck for sample 3 remeasured (07/16/2021)			101.4	719	668.3	7397.908454

Moving Forward: Procedure to Process and Assay Rock Samples from the DUNE Excavation

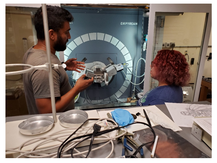
As excavation for DUNE at the 4850 level at Sanford Lab/Lead has commenced, three rocks and two quikcrete samples from different locations in the new drifts were obtained for assay prior to excavating the DUNE detector caverns. The rock and course aggregate mineral materials require course pre-crushing before milling in a motorized rock crusher to reach a state of fine powder. The fine powder sample materials are filled and compacted into standardized 125mL bottles with pre-simulated γ-ray detection efficiency and self-absorbance for fast analysis of radio-assays in the Rabbit Ge-detector.
Hundreds, possibly even thousands, of more samples will have to be assayed, controlled and mapped for radioactive content of rock, shotcrete, concrete, cryostat and detector materials throughout the entire underground caverns to be excavated.

New rock samples from DUNE excavation:

Crushing the rocks (stage 1):



Fine rock crusher (stage 2):



XRD (and XRF) analytical instruments at Mineral Industries building at SD Mines to infer chemical composition of minerals (requires fine powder samples)

Same rock samples after crushing being fine powder samples in bags (discoloration observed compared to original rocks above):

Fast loading bottled samples into the 2 ton shielded Rabbit Ge-detector chamber for γ-ray assay

Re-measured bottled samples from the DUNE test blast site inside the Rabbit Ge-detector's assay chamber

Conclusions:

The developed time dependent stability correction for simplified and more accurate data analysis of the Rabbit Ge-detector at SD Mines, as well as the improvements for faster dewar fillings with liquid nitrogen for Ge-crystal cooling, will greatly benefit radiological assays for DUNE and will enable a very high throughput of samples. This process of analysis will continue to take place daily for years to come, providing ample assay data to control and map background radiation from the cavern walls, the cryostat and detector to inform computer simulations and aid the DUNE project in reaching all of its physics goals.